**Naval Research Laboratory**

**Washington, DC 20375-5320**

**NRL/MR/5327--97-7978**


# Air/Surface Channel Isolation in the AN/SPQ-9B Radar: Diplexer Test Results


GREGORY C. TAVIK
BEN CANTRELL
MICHAEL D. LIVINGSTON

*Advanced Radar Systems Branch*
*Radar Division*



September 30, 1997

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



| 1. AGENCY USE ONLY (*Leave Blank*) | 2. REPORT DATE | 3. REPORT TYPE AND DATES COVERED |
|---|---|---|
| | September 30, 1997 | |

**4. TITLE AND SUBTITLE**

Air/Surface Channel Isolation in the AN/SPQ-9B Radar: Diplexer Test Results

**5. FUNDING NUMBERS**

PE 64755N
PR V0166

**6. AUTHOR(S)**

Gregory C. Tavik, Ben Cantrell, and Michael D. Livingston

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**

Naval Research Laboratory
Washington, DC 20375-5320

**8. PERFORMING ORGANIZATION REPORT NUMBER**

NRL/MR/5327--97-7978

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

Program Executive Office
Theater Air Defense
2531 Jefferson Davis Highway
Arlington, VA 22217-5000

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

**11. SUPPLEMENTARY NOTES**

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**

Approved for public release; distribution unlimited.

**12b. DISTRIBUTION CODE**

A

**13. ABSTRACT** (*Maximum 200 words*)

A method for reducing cross-talk interference generated on receive between the Air and Surface Channels of the AN/SPQ-9B radar is described. The method utilizes a diplexer circuit that is placed prior to a transmit/receive limiter (TRL) for each channel so that the Air and Surface Channel echoes, which are transmitted on different frequencies, are processed by two completely separate receiver chains. In this way, strong clutter echoes passing through front end components that are near saturation in one channel will not generate inter-modulation tones which could appear in the other channel's passband. Results of this method tested with NRL's AN/SPQ-9B advanced development model (ADM) radar show a 10 to 30 dB reduction of cross-talk generated on receive due to strong clutter echoes at close range.

**14. SUBJECT TERMS**

AN/SPQ-9B radar
Channel isolation
Diplexer

**15. NUMBER OF PAGES**

16

**16. PRICE CODE**

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| UNCLASSIFIED | UNCLASSIFIED | UNCLASSIFIED | UL |

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18
298-102

# CONTENTS


1. INTRODUCTION 1
2. AIR/SURFACE CHANNEL CROSS-TALK INTERFERENCE 1
3. CROSS-TALK GENERATION ON RECEIVE 2
4. DIPLEXER TESTING AND RESULTS 2
5. IDLER PULSE TEST RESULTS 3
6. PRE-PRODUCTION PLANNED IMPROVEMENT (P3I) 3
7. SUMMARY 3
8. REFERENCES 3

# AIR / SURFACE CHANNEL ISOLATION IN THE SPQ-9B RADAR: DIPLEXER TEST RESULTS

## 1. INTRODUCTION

The AN/SPQ-9B advanced development model (ADM) radar, a test-bed for the AN/SPQ-9B, has been designed and tested by NRL. The AN/SPQ-9B radar contains two separate channels: an Air Channel for detection and tracking of fast moving targets such as aircraft and missiles, and a Surface Channel for tracking slower targets such as small boats. These two channels are transmitted on different frequencies at different pulse repetition frequencies (PRF) through the same TWT transmitter at separate times. (The 250 ns Surface Channel pulse follows the (approx.) 1 us Air Channel pulse after about 100 ns of "off" time.) This arrangement gives rise to cross-talk between the channels unless some precautionary measures are taken.

NRL has recently conducted testing with the AN/SPQ-9B ADM radar and has determined that this cross-talk interference may be generated during transmit due to non-linearities in the TWT transmitter, and also during reception of strong echoes at close range possibly due to a slow recovery time of the transmit / receive limiter (TRL). A solution to the latter problem has been demonstrated and test results are presented in this report. It is assumed that the reader has some familiarity with the AN/SPQ-9B radar and so only a very brief overview is given here. For a more detailed overview of the radar, see Reference [1].

## 2. AIR/SURFACE CHANNEL CROSS-TALK INTERFERENCE

Cross-talk between the Air and Surface Channels may occur in both directions, that is from the Air Channel *to* the Surface Channel and from the Surface Channel *to* the Air Channel. However, since the Air channel is more sensitive than the Surface Channel and the spectrum of the Surface Channel is much wider than the Air Channel's spectrum after transmit, the cross-talk observed in the Air Channel due to the Surface Channel is generally more severe. This report is therefore concerned only with cross-talk interference that appears in the Air Channel due to the Surface Channel.

The Surface Channel cross-talk (interference) manifests itself in the Air Channel as shown in the ambiguity diagram in Figure 3. The four large lobes noted in the figure are spaced 4 kHz apart, which is identical to the Surface Channel PRF. A fifth lobe is masked by the Air Channel clutter return at zero Doppler. These spectral lobes appear in the Doppler space coincident with large Air Channel clutter echoes and are reported as targets by the CFAR detection algorithm. Given the Surface Channel's highly discernible interference pattern, this cross-talk could be easily identified by the CFAR detection algorithm and not reported as targets. However, this cross-talk still presents a problem in that it could mask a target in the same range cell that would otherwise be detected. For this reason, NRL believes that the cross-talk must be reduced to a minimum *prior* to formation of the ambiguity diagram and CFAR detection.

Manuscript approved August 21, 1997.

## 3. CROSS-TALK GENERATION ON RECEIVE

NRL has worked closely with Northrop Grumman Norden Systems (NGNS) to eliminate this cross-talk that is generated during transmit by the highly nonlinear TWT. Through methods of pulse shaping, saturation calibration, and maintenance of extremely "clean" LO tones in the exciter and receiver, NRL and NGNS have shown that sufficient isolation can be achieved. However, this condition is true only as long as the front end of the receiver is not saturated. Recent testing by NRL has revealed another potential source of cross-talk generation in the receiver up to and including the first mixer. This cross-talk may be generated by Air and Surface Channel echoes from very strong clutter simultaneously entering the antenna port creating a saturation condition in many parts of the receiver where signals from both channels are present. This list most notably includes the TRL (which may still be recovering from transmit shortly after the receiver has turned on), low noise amplifier (LNA), and first mixer. These components, when driven near their 1 dB compression points, will generate inter- (or cross-) modulation tones that fall in each other's passbands. These tones increase the amount of cross-talk observed after signal processing and may generate false target reports.

## 4. DIPLEXER TESTING AND RESULTS

In order to reduce the amount of cross-talk generated by each of the components, NRL has designed, built, and tested three diplexer circuit configurations that were placed prior to each of the three components listed above, or in some combination (see Fig. 1). The diplexers consist of a circulator, and one or two filters which provide a low loss splitting/filtering configuration (see Fig. 2). In this way the two channels' signals are separated prior to each component. Of the two configurations shown in Fig. 1, the last configuration (#2) with the diplexer inserted prior to the TRL, achieved the best results. Only a minimal improvement was observed when the diplexer was placed in front of the LNA and first mixer (configuration #1). Additional filters were placed prior to the first mixers as shown in configurations #1 and #2, however these provided negligible improvement. So the TRL appears to be the major contributor to cross-talk generated on receive among the three.

During NRL's most recent testing with the AN/SPQ-9B ADM radar at Wallops Island, Virginia, improvements on the order of 10 to 30 dB were observed by placing the diplexer prior to the TRL. Figure 3 shows an Air Channel ambiguity diagram illustrating the cross-talk when the radar is in its current configuration (see Fig. 1), without a diplexer. The magnitude of the cross-talk is about -42 dB relative to the maximum allowable received power. Figure 4 shows an ambiguity diagram collected from the same azimuth as Figure 3, 239.8$^{o}$ (true north) which is over land, only this time the diplexer has been inserted prior to the TRL. The magnitude of the cross-talk shown is -68 dB, a reduction of 26 dB. All data were collected with the Air and Surface frequencies separated by 480 MHz. (The two channels were separated by this large amount due to availability of the filters used in the diplexer; further testing at a separation of 160 MHz will be conducted when a second filter is received.) Figures 5 and 6 provide a similar comparison (15 dB cross-talk reduction) looking south along the beach at 210.5$^{o}$. Figures 7 and 8 give another comparison (20 dB cross-talk reduction) looking over land again at 240.4$^{o}$. Figure 9 illustrates Surface / Air Channel isolation near 90 dB for clutter that is farther from the radar but very near saturation.

Most of the improvement was observed for very close-in clutter (<0.8 nmi.). For this reason, NRL believes that cross-talk interference generated on receive is primarily due to slow TRL recovery time. False alarms were reduced by a factor of 2 during a 1 minute (30 scans) interval over a region covering 240 degrees in azimuth. Most (90%) of the false detections occurred within 1.7 miles from the radar (99% within 3.1 miles), assuming very few false detections are due to multiple interval clutter at ranges greater than 4 miles. Most (90%) were less than 3 dB above the CFAR threshold (99% were <8 dB above threshold). It should be noted that this environment is a worst-case scenario due to the ADM antenna's low height (25 feet above ground level), and the numerous (>50) large towers, buildings, and other structures nearby on Wallops Island.

## 5. IDLER PULSE TEST RESULTS

The Air Channel PRF is much higher (about 8 times) than the Surface Channel PRF. However, the pulses of these two channels are transmitted through the same TWT. In order to keep the amount of receiver blind time to a minimum, the Surface Channel pulse is transmitted shortly (about 100 ns) after every $N^{th}$ (say N equals 8) Air Channel pulse such that the Surface Channel PRI is an integer number of Air Channel PRIs long. Recall that the Air and Surface Channel pulses are transmitted on different carrier frequencies. During the N-1 (say 7) pulses between each Surface Channel pulse, an Idler pulse is transmitted on a third frequency. This Idler pulse is different from the Surface Channel pulse only in frequency. The function, therefore of the Idler pulse is to take the place of the Surface Channel pulse during the additional Air Channel transmit times so as to maintain a constant duty cycle in the transmitter. Recently, the need for the Idler pulse has been called into question.

A test was conducted in which the Idler pulse was eliminated (but the width of the transmitter grid pulse, which turns on the electron beam, remained fixed). It was observed that transmitter stability suffers a great deal if the Idler pulse is not transmitted. Figure 10 is an ambiguity diagram showing the resulting increase in cross-talk. In fact, so many false detections were created that the signal processor could not keep up and began throwing out many of the dwells. It appears that by not transmitting the Idler pulse in between Surface pulses, the transmitter power supplies are modulated at the Surface Channel PRF as the load changes. This in turn modulates the Air pulse train at the Surface Channel PRF.

## 6. PRE-PRODUCTION PLANNED IMPROVEMENT ($P^3I$)

If NGNS experiences problems with cross-talk on receive while conducting tests with the AN/SPQ-9B production proof kits (PPK), the diplexer solution described above would be a relatively inexpensive and simple solution. Additional above decks equipment would include a diplexer (2 filters @ $1K each, 1 circulator @ $3K), TRL ($6K), LNA ($2K), and an additional receive waveguide run ($1K). The additional LNA may not even be needed if the current built-in spare is utilized. The diplexer adds very little additional loss to the system because the bandpass filter (0.5 dB loss) which currently precedes the LNA could be removed and the diplexer (0.8 dB loss) put in its place, increasing the receiver noise figure by only 0.3 dB (the loss of the circulator). The diplexer filters would accomplish the same objective as the original bandpass filter but would probably leave a small "hole" in the middle of the entire transmission band creating a "high" and "low" band. Each of the two bands could be used by either the Air or Surface Channel if an additional switch ($1K each) is added prior to each channel's first mixer.

## 7. SUMMARY

After many trials, a method to significantly improve the Air / Surface Channel isolation on receive has been demonstrated. Using a diplexer, the Air and Surface Channel echoes from strong clutter may be filtered prior to the TRL, greatly reducing the cross-talk between them, especially at close range. This diplexer circuit is relatively easy to implement and not overwhelmingly expensive (about $15K). Now that a solution is available, a decision may be made whether it is needed for use in the AN/SPQ-9B production radar from NGNS after PPK testing.

## 8. REFERENCES


[1] B. H. Cantrell, L. M. Leibowitz, et. al., "Advanced Development Model of the AN/SPQ-9(I) Radar," NRL Memo Report 7607, 3 October 1994.

[2] W. J. Cheung, J. P. Clark, et. al., "AN/SPQ-9(I) Radar Processor Functions and Software," NRL Memo Report 7608, 3 October 1994.

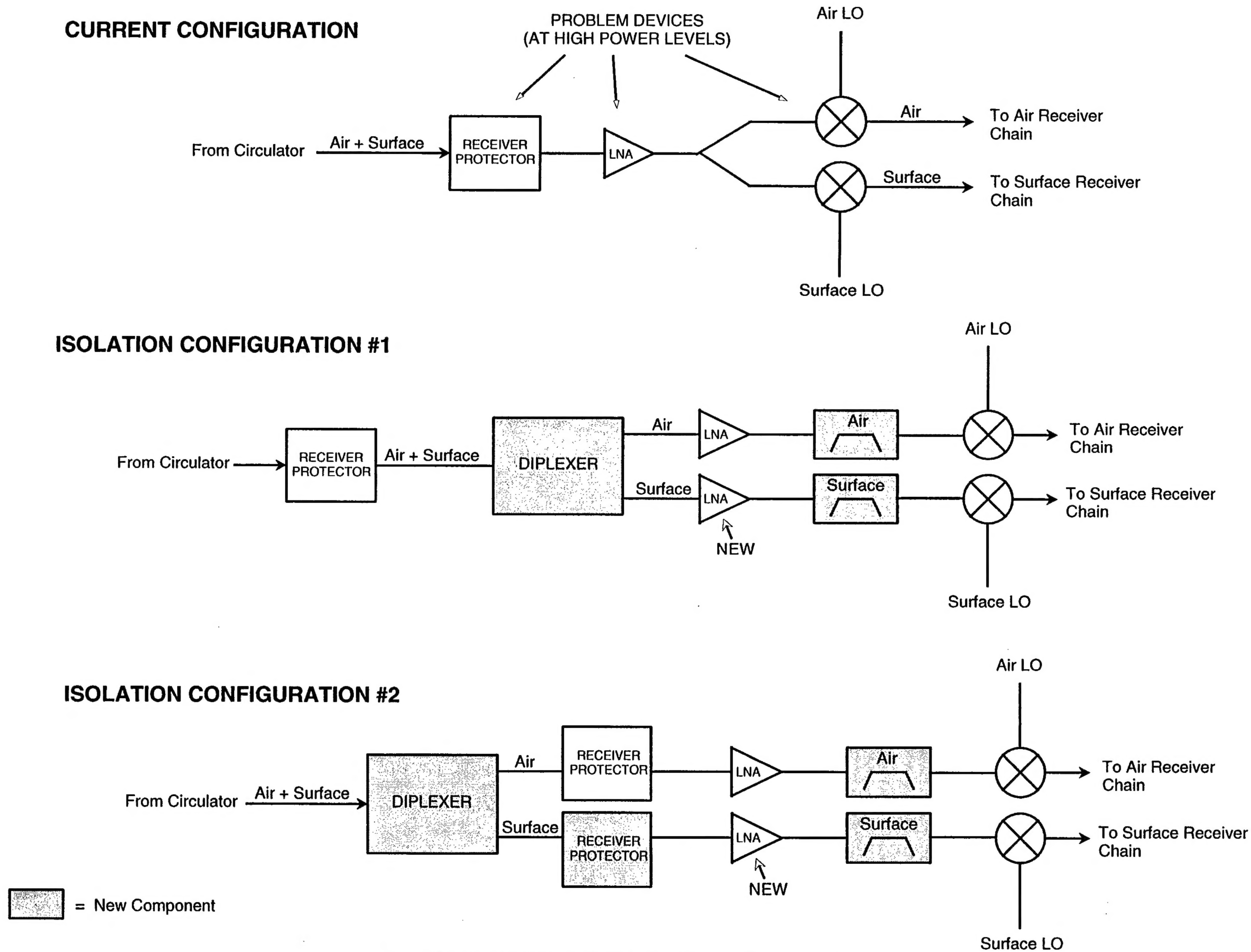
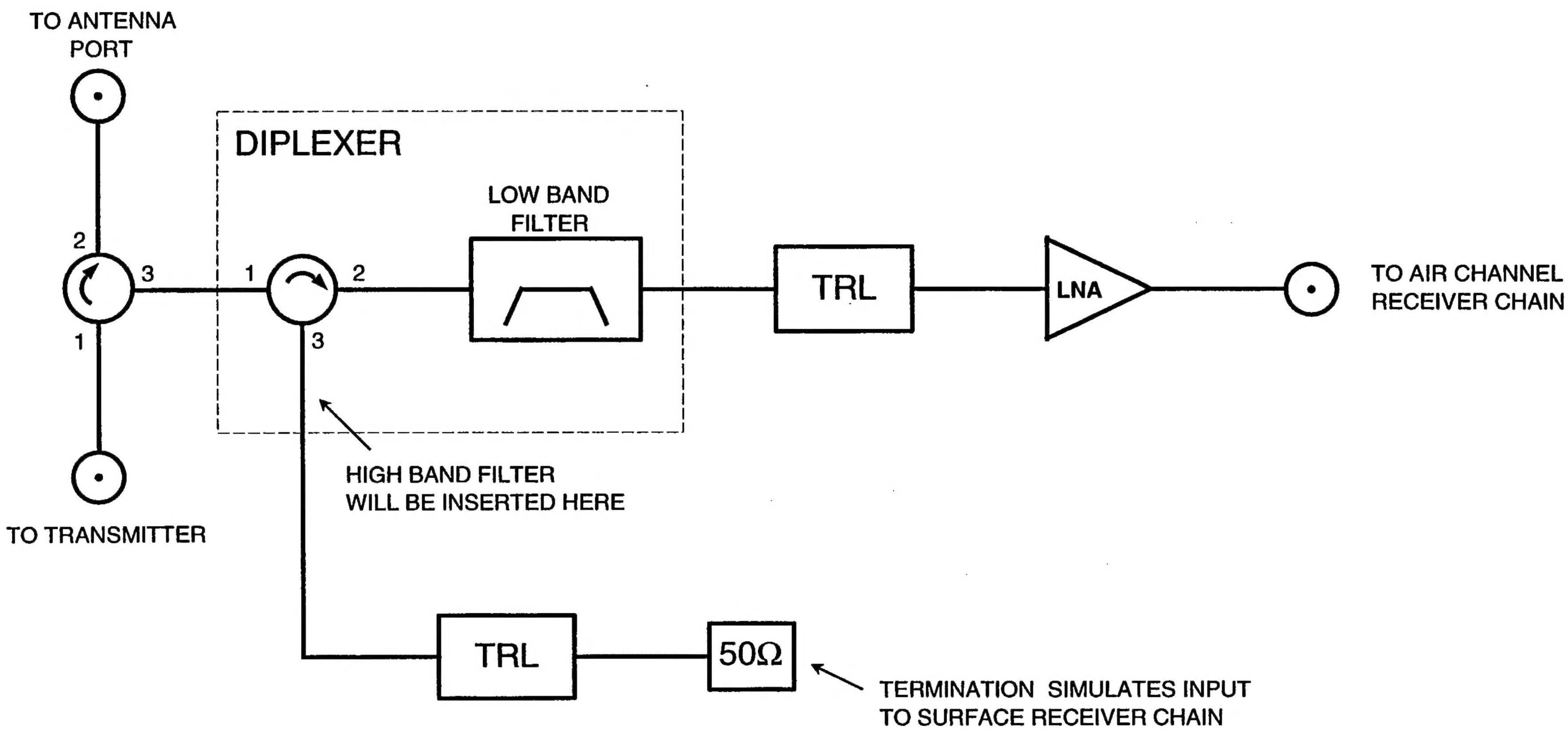



Fig. 1 - Various hardware configurations tested by NRL to reduce cross-talk between the Air and Surface Channels in the SPQ-9B ADM radar.




<u>Frequency Allocation</u>

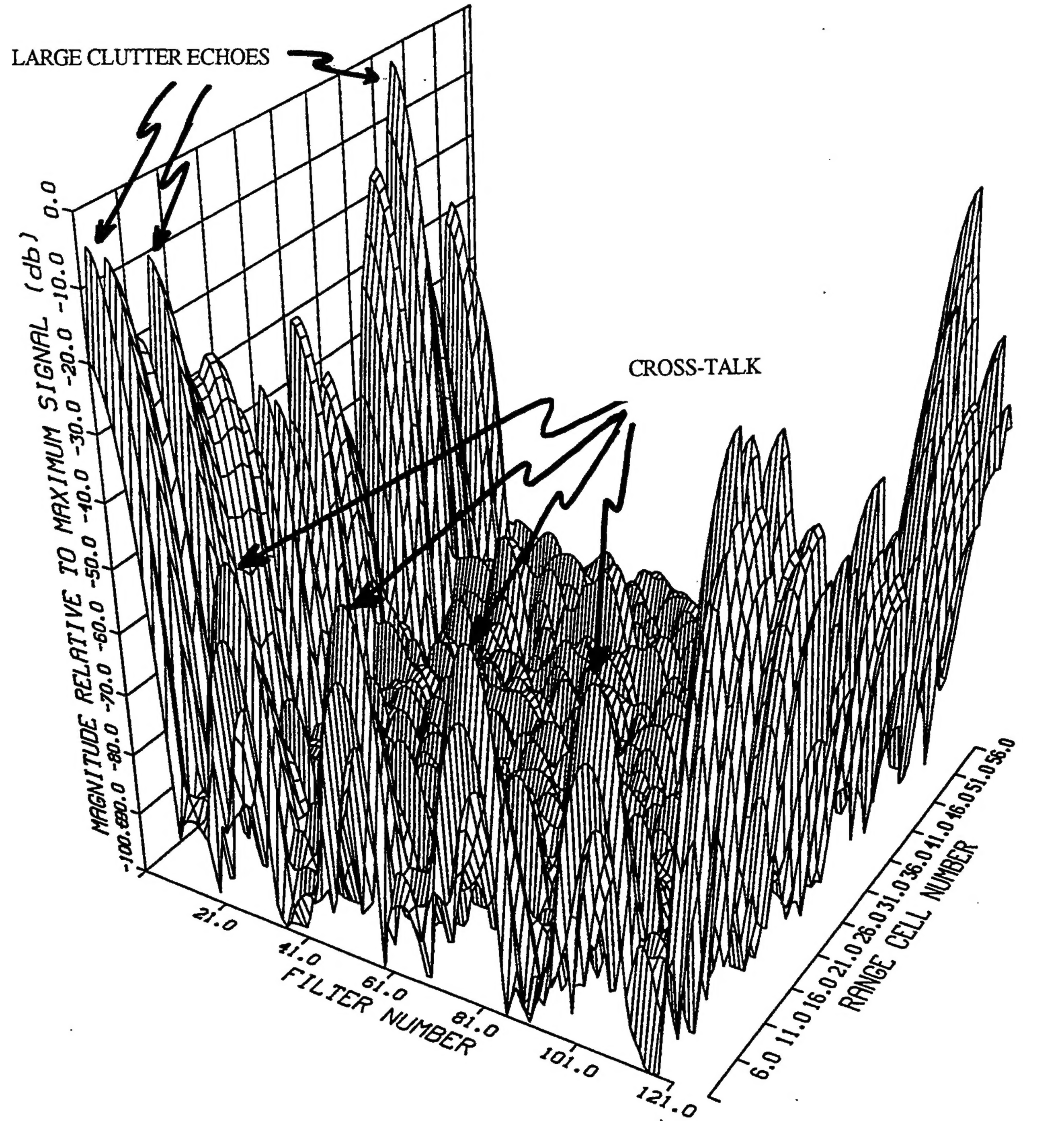
Air Channel: Low Band

Surface Channel: High Band

Idler Frequency: High Band

Fig. 2 - Construction of diplexer circuit is shown as it was inserted into the SPQ-9B ADM receiver path.

| IRIG TIME | AZIMUTH | PRI | FREQ |
|---|---|---|---|
| 2139311.000000 | 239.87140 | $5.04 \times 10^{-5}$ | 5 |




1/24/97

Fig. 3 - Air Channel ambiguity diagram showing large clutter echoes and Surface Channel cross-talk when using the current radar configuration *without* the diplexer. This data was collected at Wallops Island while looking over land.

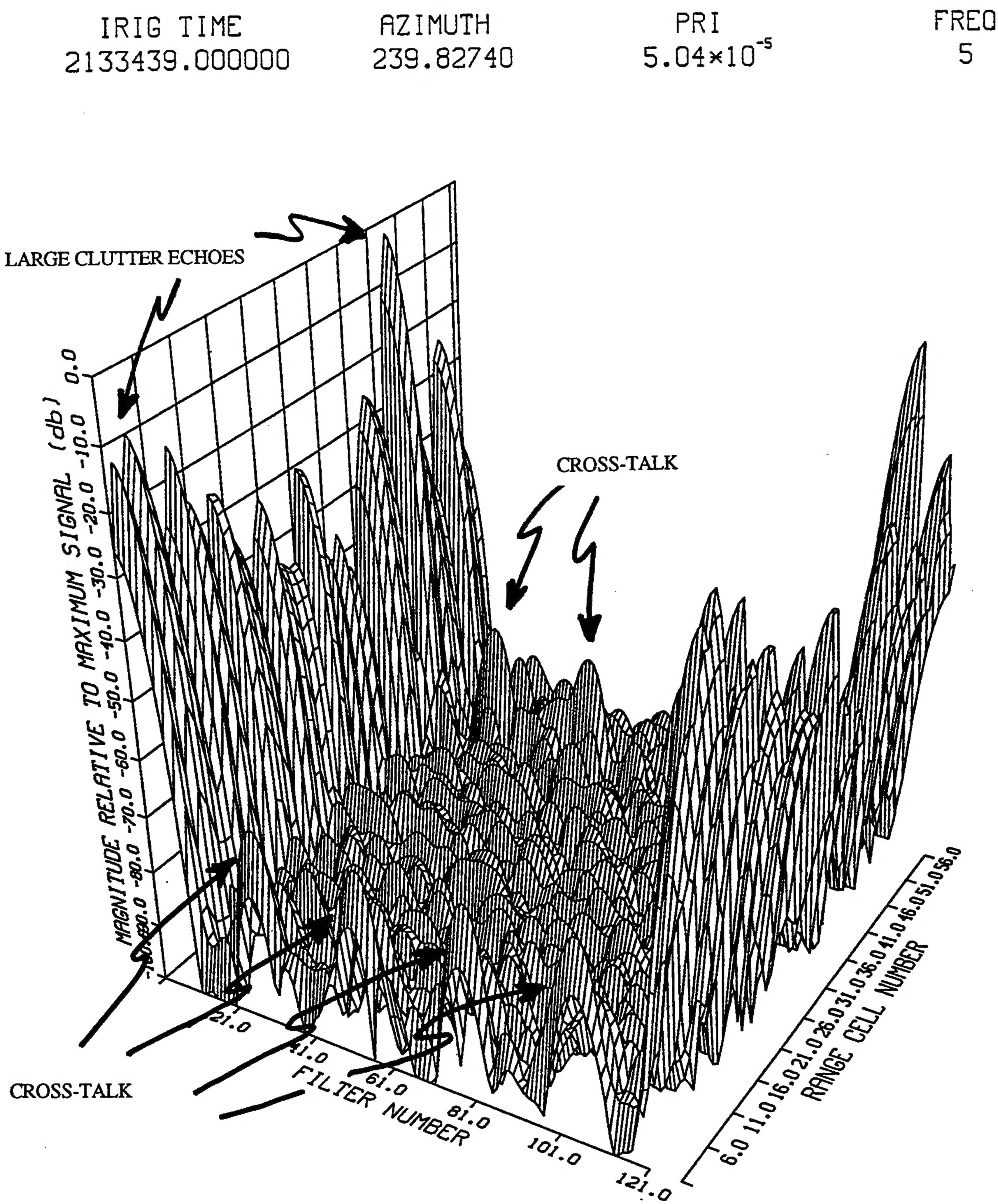



Fig. 4 - Air Channel ambiguity diagram showing large clutter echoes and Surface Channel cross-talk when using the new radar configuration *with* the diplexer. Compare this data with Fig. 3, which was collected from the same azimuth.

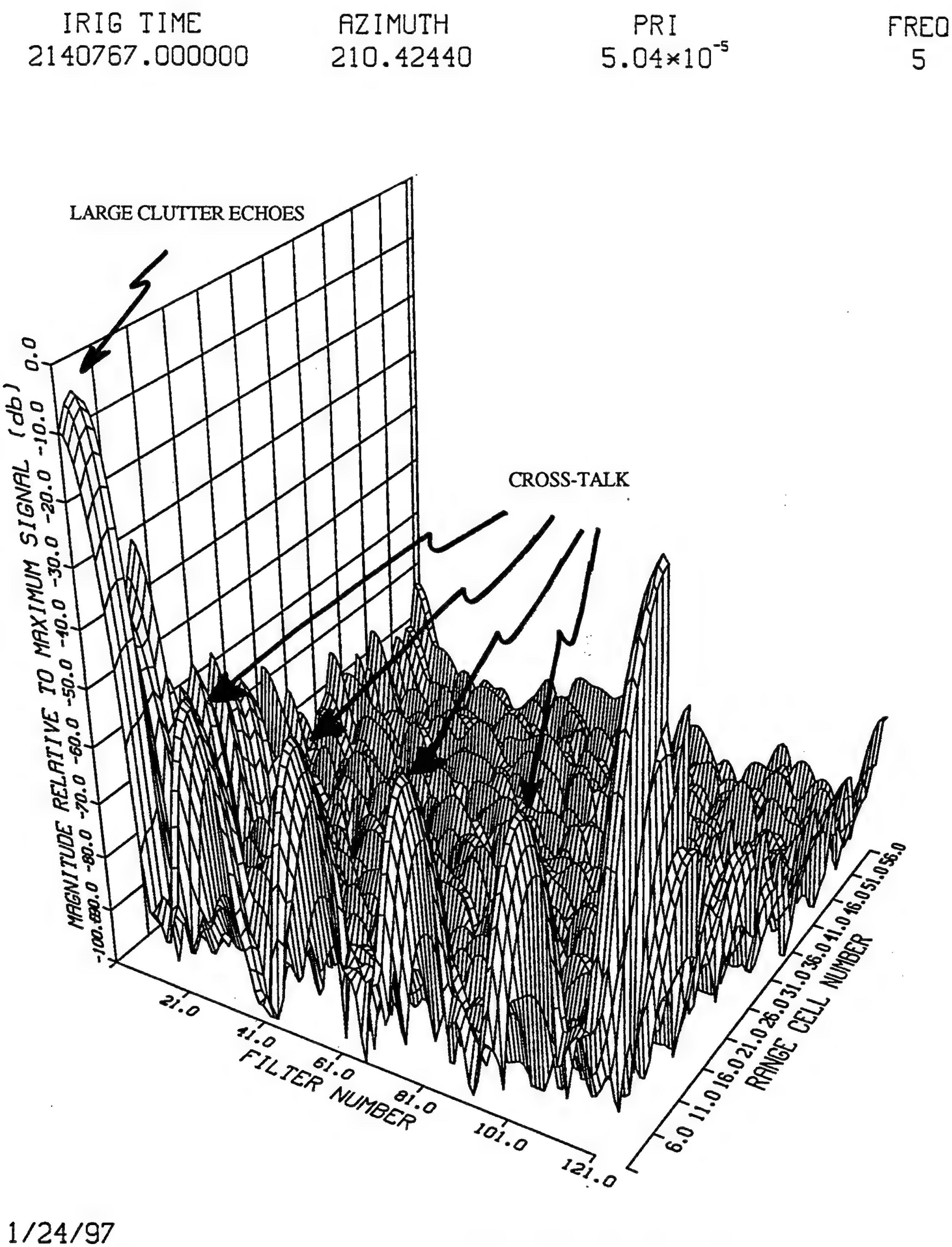



Fig. 5 - Air Channel ambiguity diagram showing large clutter echoes and Surface Channel cross-talk when using the current radar configuration *without* the diplexer. This data was collected at Wallops Island while looking along the beach.

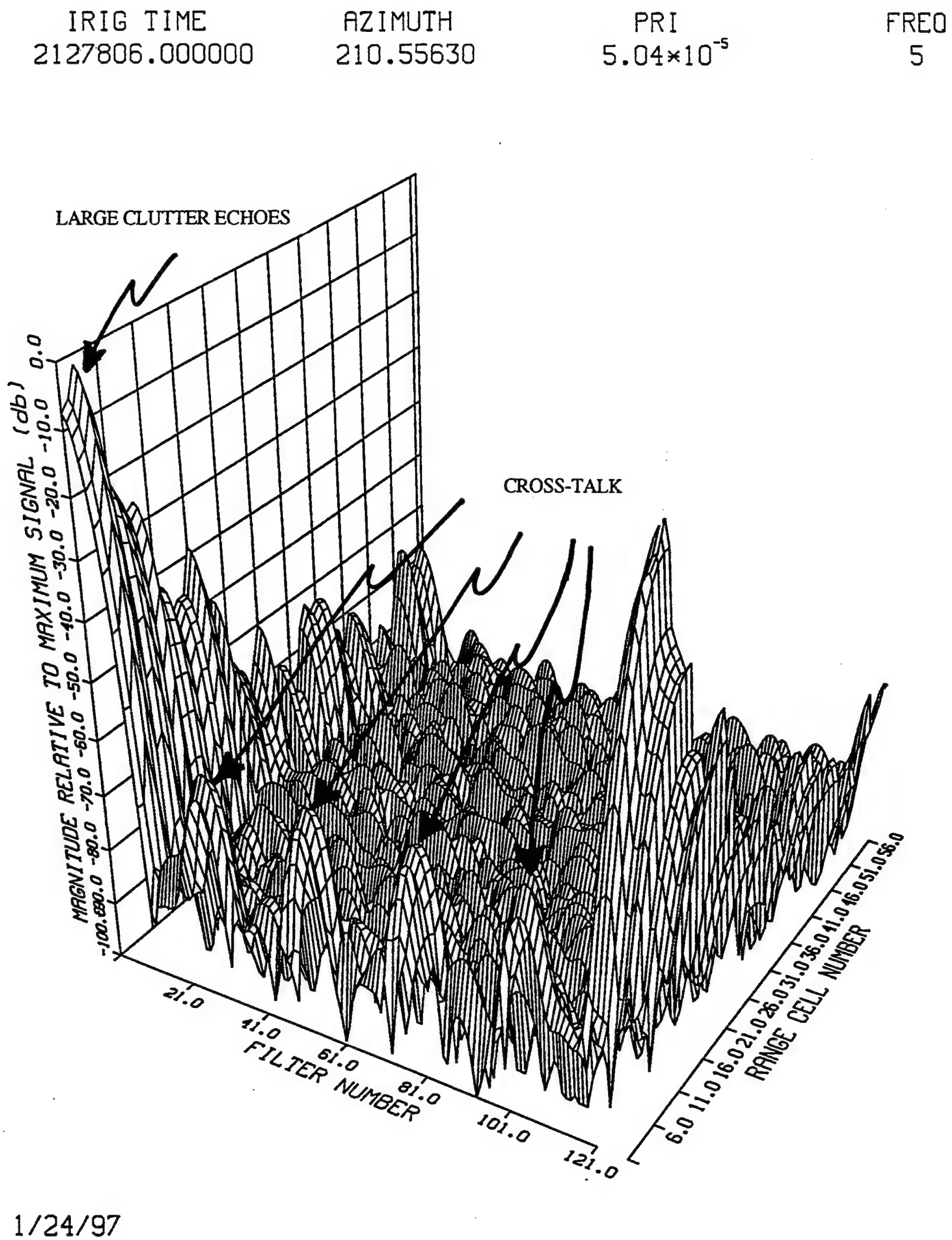



Fig. 6 - Air Channel ambiguity diagram showing large clutter echoes and Surface Channel cross-talk when using the new radar configuration *with* the diplexer. Compare this data with Fig. 5, which was collected from the same azimuth.

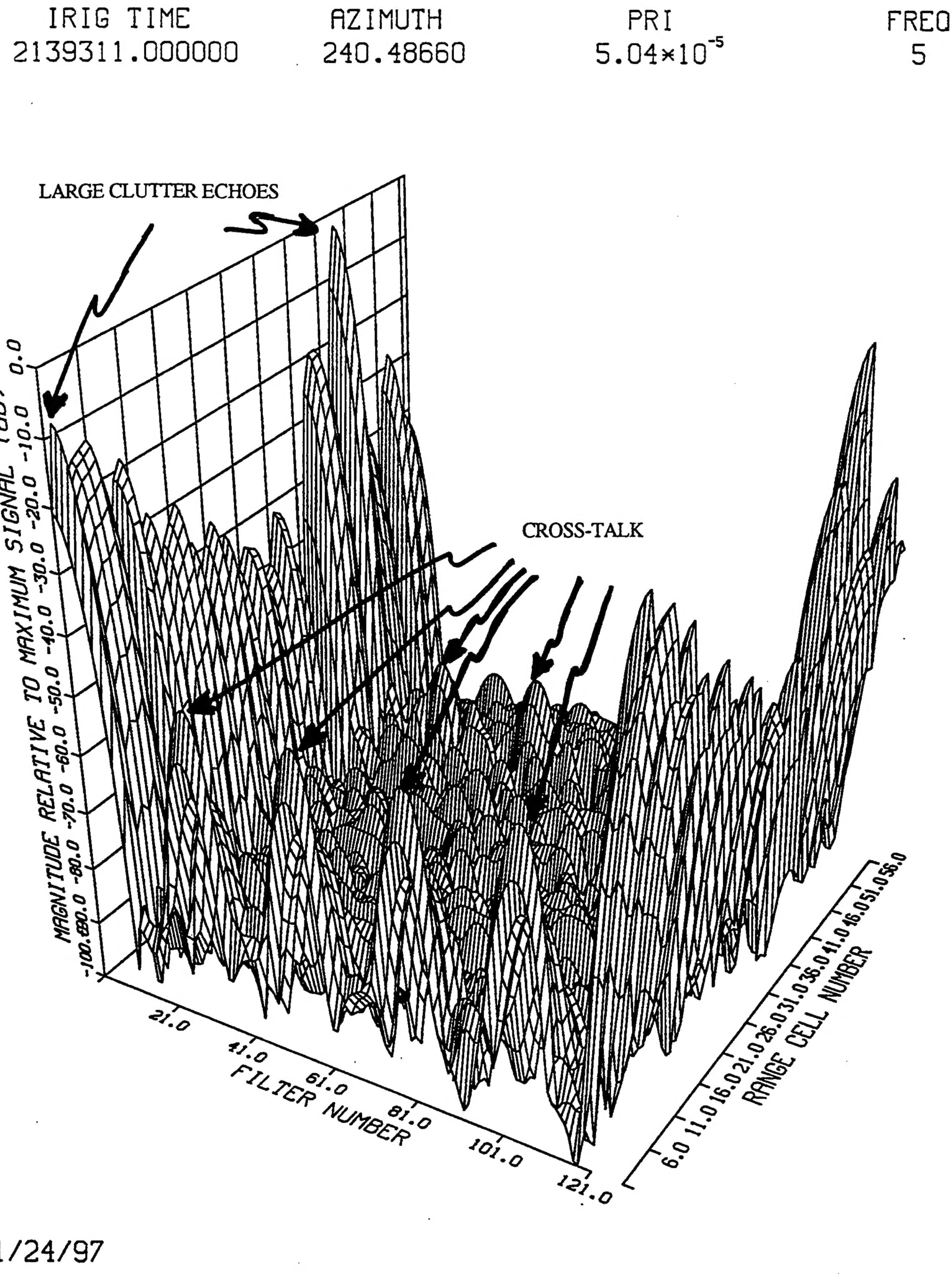



Fig. 7 - Air Channel ambiguity diagram showing large clutter echoes and Surface Channel cross-talk when using the current radar configuration *without* the diplexer. This data was collected at Wallops Island while looking over land.

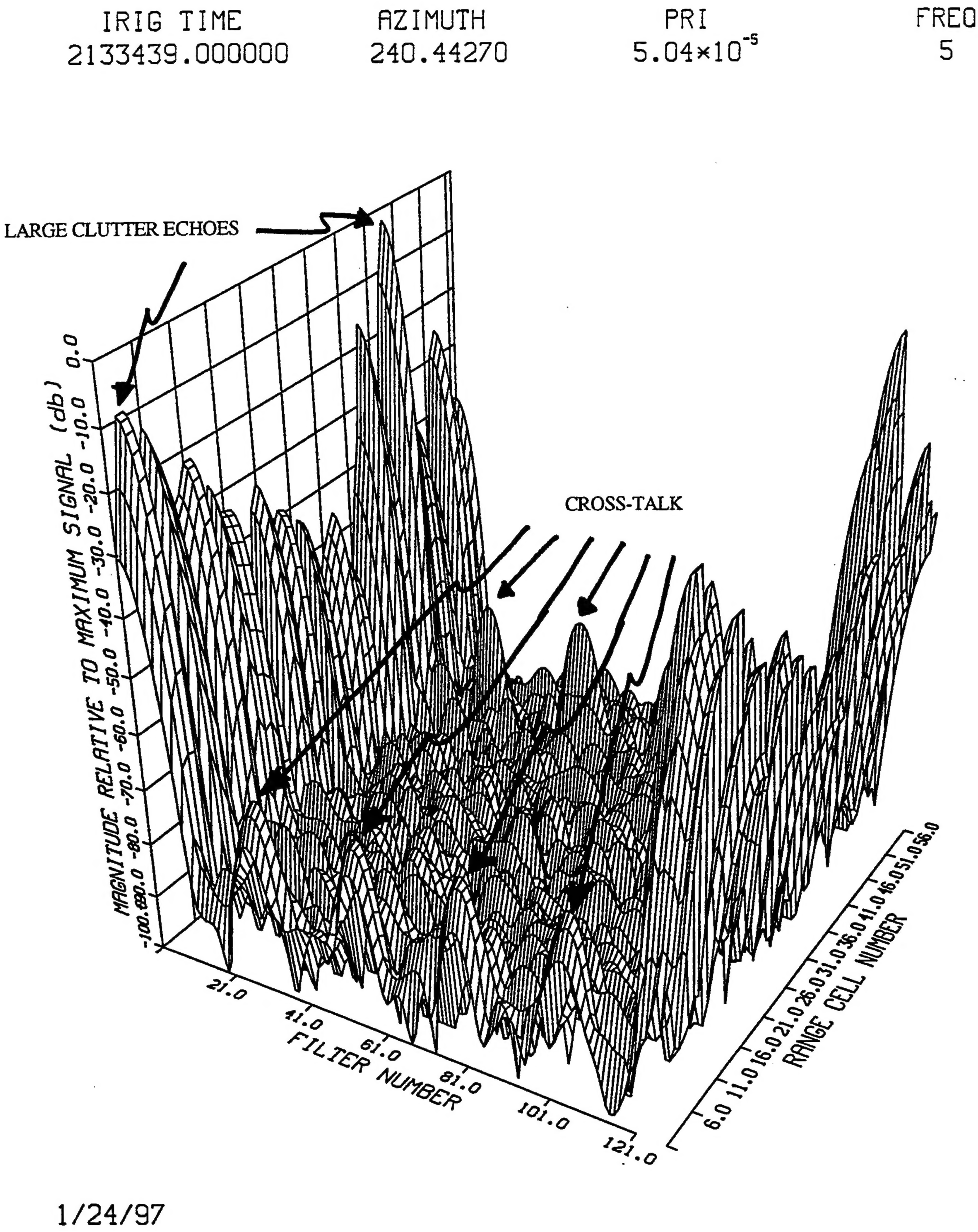



Fig. 8 - Air Channel ambiguity diagram showing large clutter echoes and Surface Channel cross-talk when using the new radar configuration *with* the diplexer. Compare this data with Fig. 7, which was collected from the same azimuth.

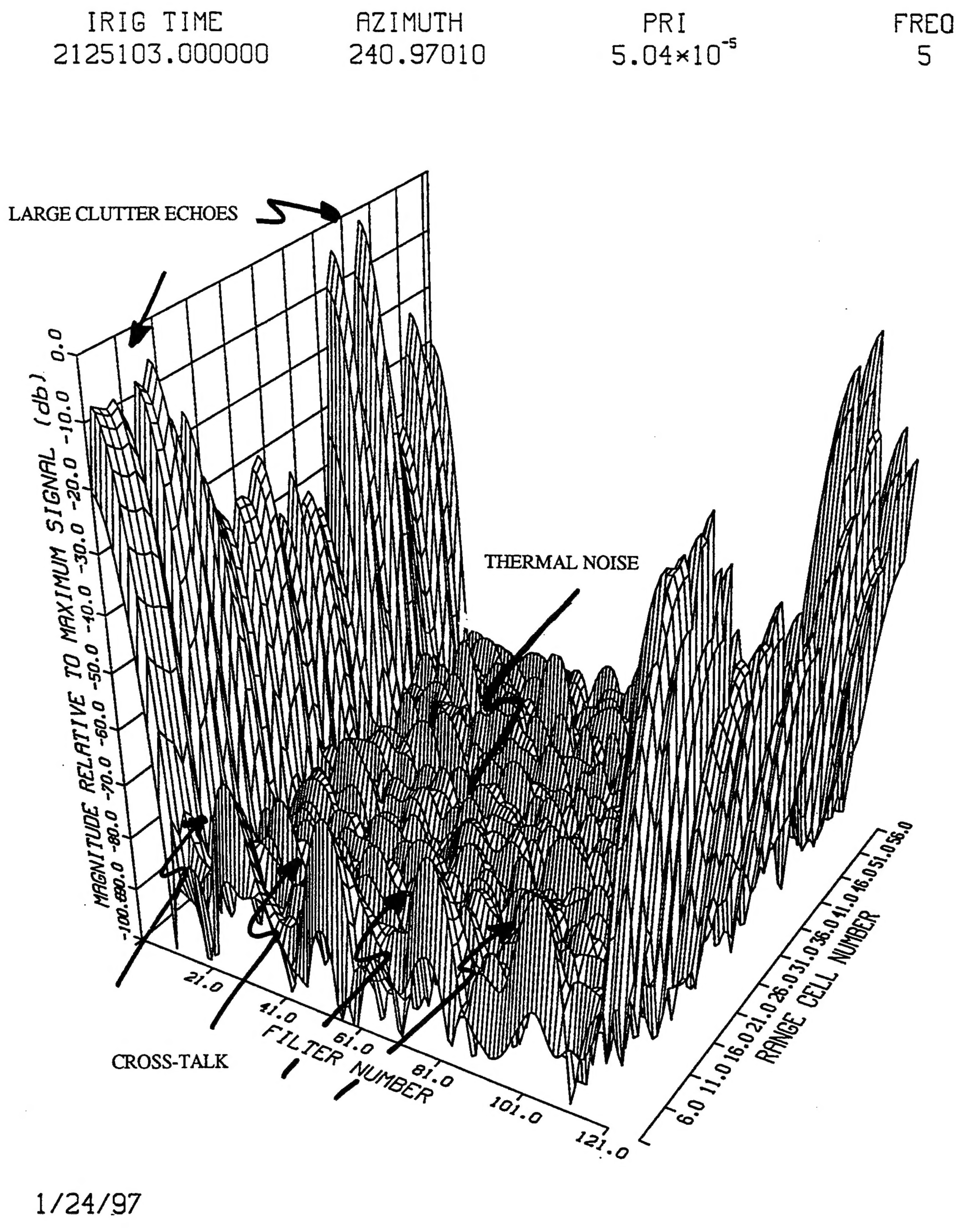
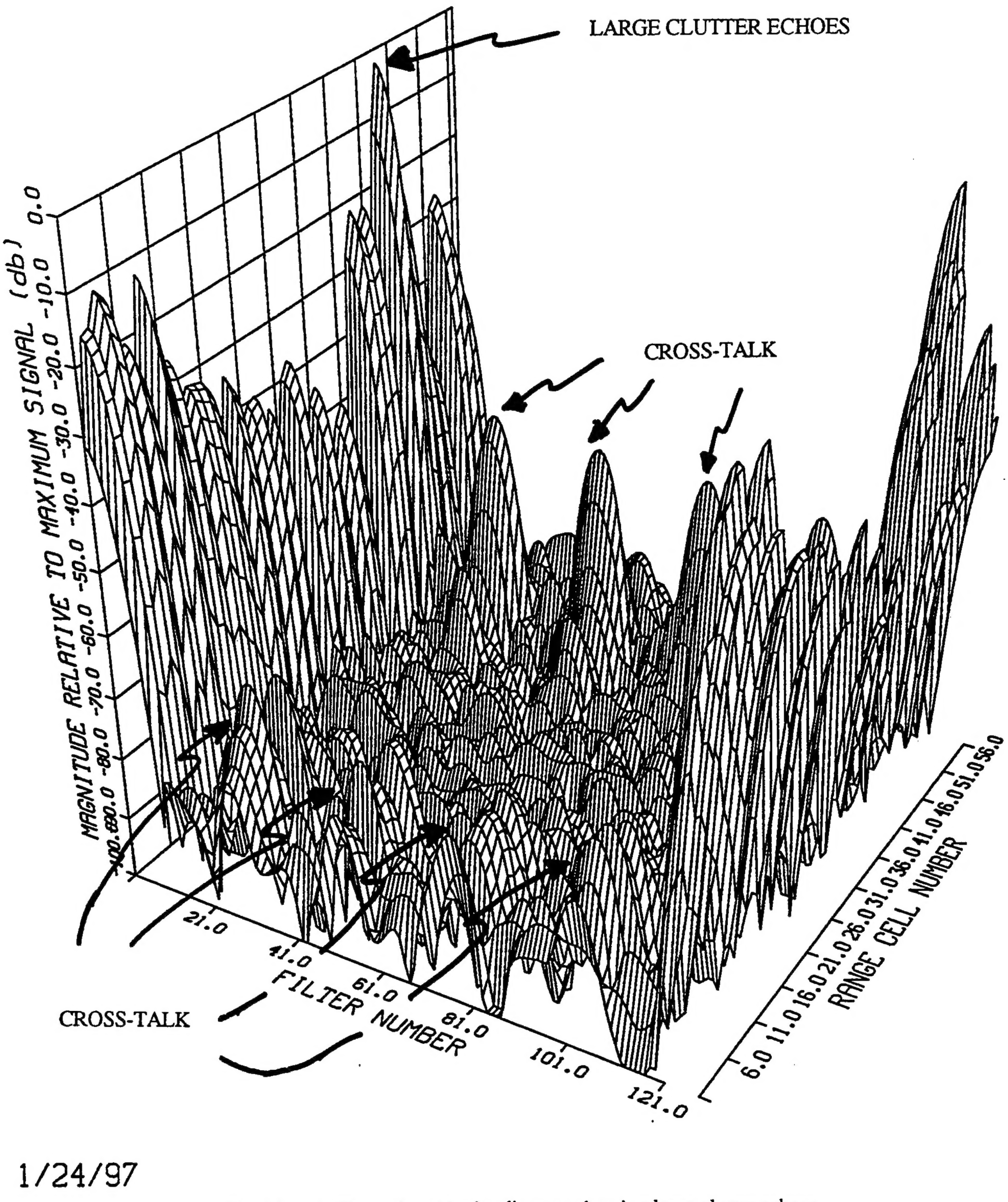



Fig. 9 - Air Channel ambiguity diagram showing large clutter echoes and Surface Channel cross-talk when using the new radar configuration *with* the diplexer. Notice the reduction in cross-talk to thermal noise at far range indicating near 90 dB isolation of Air and Surface Channels. Compare this data with Fig. 7, which was collected from nearly the same azimuth.

| IRIG TIME | AZIMUTH | PRI | FREQ |
|---|---|---|---|
| 2132218.000000 | 240.09110 | $5.04\times10^{-5}$ | 5 |




1/24/97

Fig. 10 - Air Channel ambiguity diagram showing large clutter echoes and Surface Channel cross-talk when using the new radar configuration *with* the diplexer but *without* transmitting the Idler (Unused) pulse. Notice the large increase in cross-talk. Compare this data with Fig. 4, which was collected from nearly the same azimuth.